An integrated fine coal preparation technology: the GranuFlow Process

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Abstract

In order to alleviate the problems of fine coal handling and processing and to enhance the utilization of fines by utilities, US Department of Energy's (DOE's) Federal Energy Technology Center (FETC) developed and patented the GranuFlow Process. This paper summarizes recent test results of the GranuFlow Process with pilot-scale and plant-scale centrifuges in commercial plants. The main benefits of the GranuFlow Process are that it can potentially reduce the amount of waste coal that is stored in refuse impoundments, reduce the moisture content of the final clean coal product, improve handling by converting wet sticky fines to a granular, free-flowing material, prevent frozen coal problems in rail cars, and reduce the dustiness and fugitive dust losses during transportation and handling. Since Orimulsion is a low cost bitumen emulsion, this technology provides the coal industry with a cost-effective technology for fine coal processing. © 2000 Published by Elsevier Science B.V. All rights reserved.

Keywords: dewatering; bitumen; emulsion; microagglomerate; centrifuge; fine coal; moisture reduction; dust reduction; GranuFlow Process

1. Introduction

Coal preparation is used to upgrade as-mined coal before it is utilized by the end user, primarily electric utility power plants. It reduces the amount of noncombustible mineral impurities, acid rain precursor sulfur-bearing minerals and hazardous trace elements, and generally produces more uniform, higher energy content fuels. Most

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conventional and advanced coal cleaning processes, however, involve the use of water and dewatering (Parekh, 1987) of the fine clean-coal is often a problem. Utility companies are concerned not only with the lower Btu content of the resulting wet, cleaned coal, but more importantly, with its handleability problems (stickiness, dustiness, freezing) (Arnold et al., 1992). Both moisture and handleability problems are exacerbated in the portion of the coal with the smallest particles, the fines. As a result, most utility coal contracts have limits on the amount of moisture and the quantity of fines in the final coal shipments, making it difficult for coal preparation plants to process the fines and include them in the final product.

In order to alleviate the problems of fine coal processing and enhance the utilization of fines by utilities, Federal Energy Technology Center (FETC) developed an innovative process, called the GranuFlow Process. The process requires the addition of a small amount of specially selected binding material, such as an aqueous emulsion of asphalt, bitumen, or heavy oil, and mixes it with the fine clean-coal slurry before dewatering. The binding material becomes incorporated into the product to form microagglomerates when the emulsion breaks with fine coal slurry. The clean-coal product is converted into randomly-sized, dustless fragments or granular particles after being discharged from the dewatering process. Such a product has only moderate compressive strength, but the great majority of the "dust" particles and moisture are sufficiently bound in the dewatered microagglomerates to mitigate the handling problems. Since the emulsion droplets bind selectively with the hydrophobic coal particles into granular products, the process also rejected ash forming material into centrifuge effluent water that provided further beneficiation effects. There were two patents obtained for this process. In the first patent (Wen and Deurbrouck, 1990), a small amount of binding material (such as asphalt emulsion) was mixed with the clean coal slurry from a fine coal cleaning process (e.g., froth flotation) before it was fed to a dewatering device. Early work, referred to as the "In Situ Cake Hardening Process" successfully demonstrated the feasibility of the process using laboratory-scale vacuum filtration (Wen, 1990; Wen and Deurbrouck, 1990) and focused on the effects of mixing intensity, slurry temperature, coal particle size, emulsion composition and dosage, and drying procedure on the performance of dewatering process. The results indicated that the addition of bitumen emulsion to a clean-coal slurry improved filtration rate, reduced filter cake moisture, and significantly reduced the dustiness of the dried filter cake.

The process was scaled up and tested in both a 15.2-cm bench-scale Bird screen–bowl centrifuge (Wen and Killmeyer, 1993; Wen et al., 1994) and a 35.6-cm Sharples high-g force solid–bowl centrifuge (Wen et al., 1995a; Wen and Killmeyer, 1996) in FETC's Solid Processing Research Facility (SPRF). The binder coats the coal particles and ultimately transforms the product into free-flowing, random-sized, dustless granular material with a lower moisture content. It was renamed the GranuFlow Process.

In searching for low cost binding agents to further improve the economic feasibility of the GranuFlow Process, the concept of using an emulsion as a flotation reagent was initiated for a second patent (Wen et al., 1995b). It was found that an emulsion of a heavy crude oil (Orimulsion) can be as effective as a binding agent as an emulsified asphalt, and can also be used effectively as a collector for fine coal flotation (Wen et al., 1993; Yang and Wen, 1998).

The main benefits of the GranuFlow Process are that it can potentially (1) reduce the amount of coal that is wasted to coal refuse impoundments, (2) reduce the moisture content of the final clean coal product, (3) improve handling by converting wet sticky fines to a granular, free-flowing material, (4) prevent frozen coal in rail cars, and (5) reduce the dustiness and fugitive dust losses during transportation and handling.

Recently, FETC performed a series of pilot-scale centrifuge dewatering tests (Wen and Killmeyer, 1997) using a 45.7-cm Decanter screen–bowl centrifuge and applying the GranuFlow Process to column flotation clean-coal concentrate at the Powell Mountain Coal Mayflower Plant. A plant-scale test (Wen and Killmeyer, 1998a,b) of the GranuFlow process was also conducted using two 91-cm Bird screen–bowl centrifuges for the dewatering and reconstitution of fine clean-coal slurry at AMVEST Coal Terry Eagle Coal Preparation Plant in West Virginia. This paper summarizes testing results of the GranuFlow Process on handleability improvement of the pilot-scale and plant-scale centrifuges tests in commercial coal preparation plants.

2. Experiment

2.1. Coals

2.1.1. Coal for the pilot-scale tests

An Upper Mason seam coal was processed at the Mayflower Coal Preparation Plant. The column flotation slurry concentrate had about 15 wt.% solids and contained 6.5 wt.% ash. The particle size was 90% passing 150 mesh (106 μm) with mean size (d_{50}) of 25 μm.

2.1.2. Coals for the plant-scale tests

The coals being washed were a mixture of West Virginia No. 2 Gas Seam and Eagle Seam, Nicholas County, West Virginia. The centrifuge feed with particle size distribution of 28 mesh (600 μm) × 0, at 9.6 wt.% ash was a combination of flotation concentrate and cyclone underflow at a ratio of approximately 1 to 3.

2.2. Bitumen emulsions

Orimulsion is a low cost (US$40 per ton) and high-Btu bitumen-in-water emulsion from Venezuela. It is being used as a fuel for power generation. The emulsion contained about 70% Orinoco bitumen, 30% water, and a trace amount of surfactant. A typical Orinoco bitumen has a heat content of about 9280 kcal/kg (16,700 Btu/lb).

2.3. Method for bitumen and fine coal slurry mixing

Previous test results indicated that static mixers gave adequate mixing; however, when bypassing the static mixer, the in-situ pipe flow mixing also gave similar results when at least 4.6-m of feeding pipe was between the emulsion feeding location and centrifuge. Mixing could be a critical factor for dispersing the emulsion into the coal–water slurry. For the application of Orimulsion in a centrifuge dewatering system, the in-situ pipe flow mixing seems adequate, so the static mixer was not necessary. However, if the system is for vacuum filtration dewatering, high-shear mixing, as reported in previous work (Wen et al., 1994), may become necessary because of different dewatering mechanisms.

2.4. Method for dust index measurement

To evaluate the performance of the GranuFlow Process for dust control, FETC adopted a simple Ro-Tap dry screening process to experimentally measure the dust index (I_i) of the cakes with a constant amount of stress applied (Wen et al., 1989). Dust reduction efficiency (E) is calculated based on the following equation.

$$E = \frac{I_0 - I_i}{I_0} \times 100$$

where, E = dust reduction efficiency of dry cake, %. I_0 = dust index of coal, cumulative weight percent of feed coal finer than 150 mesh (106 μm) by wet screening. I_i = dust index of cake, cumulative weight percent of dry cake finer than 150 mesh (106 μm) after Ro-Tapping for 5 min.

2.5. Microagglomeration

A series of particle size distributions of the −150 mesh (106 μm) feed coal to the centrifuge at eight different Orimulsion concentrations ranging from 0 to 8 wt.% are shown in Fig. 1 (extrapolated data are in dotted lines). These data reported by Wen and

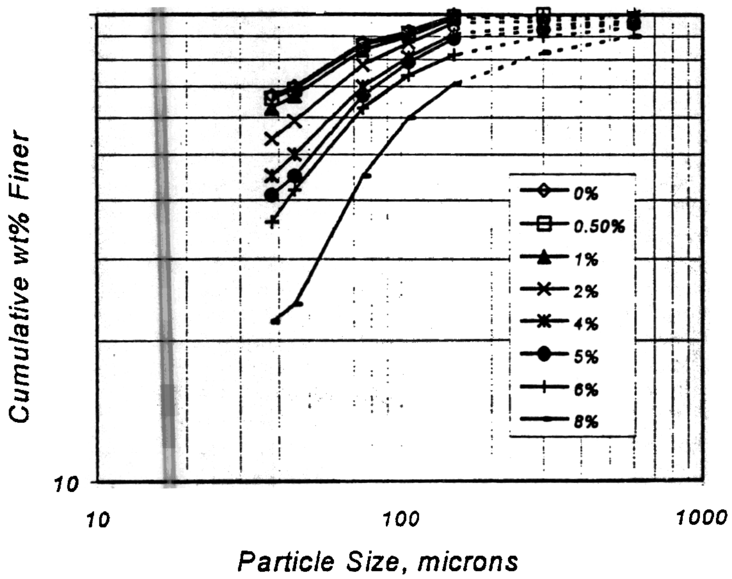

Fig. 1. Particle size distributions of −150 mesh (106 μm) centrifuge feed coal with Orimulsion treatment (wet screen analysis).

Killmeyer (1996) clearly indicate that microagglomeration occurred between fine-coal particles when the amount of bitumen emulsion was increased, coarsening the size distribution. It is believed that this microagglomerate (which is hydrophobic in nature) improved the dewatering rate, reduced the final product moisture content and product dustiness, and enhanced the product handleability.

2.6. Test facilities and procedures

2.6.1. For pilot-scale tests at Mayflower plant

FETC performed a series of pilot-scale centrifuge dewatering tests at the Mayflower plant. The centrifuge dewatering test circuit at the Mayflower plant was set up outside the plant and included a 1900-l slurry feed tank, a 19-l Orimulsion holding container, a Viking gear pump, model SG-0525-M, a 46-cm Decanter screen–bowl centrifuge, and a product conveyer. The feed tank was set on a platform 9-m above ground. The centrifuge was set on the ground about 9-m away from the feed tank. The coal slurry was gravity-fed to the centrifuge via a 5.1-cm pipe connected from the tank to the centrifuge. A tube valve, located about 0.9-m from the centrifuge feed inlet, was used to control the feed rate. Orimulsion was pumped directly into the slurry feed line about 0.3-m away from the bottom of the feed tank providing about 8.5-m on-line mixing distance. The capacity of the centrifuge was around 1 to 2 t/h of coal, and the rotation speed was at 1000 rpm which provided a force field of 226 g. The screen opening was about 28 mesh (500 μm).

The slurry feed rate to the centrifuge was kept constant at about 76 l/min which provided about 3/4 ton of coal per hour of operation. The dewatering tests started with samples without Orimulsion to obtain baseline data for the screen–bowl centrifuge dewatering. At the end of 30 min of baseline operation, the Orimulsion pump was turned on. Generally, samples of the slurry feed, dewatered product coal, and centrifuge effluent and screen effluents were collected at 10 and 20 min of operation for each test condition. Timed samples were usually taken after 20 min of operation for material balance determination. Samples were analyzed for product moisture, solids and ash contents, and product dust index.

2.6.2. For plant-scale tests at the Terry Eagle plant

Two 91-cm Bird screen–bowl centrifuges were tested for the dewatering and reconstitution of fine clean-coal slurry at AMVEST Coal Terry Eagle Coal Preparation Plant in West Virginia. The plant capacity was about 425 t/h of run-of-mine coal. The centrifuges were dewatering -28 mesh (600 μm) fine clean-coal at a feed rate of about 40–50 t/h. This centrifuge feed consisted of -100 mesh (150 μm) froth flotation concentrate at about 12–15 t/h, and the 28 mesh (600 μm) $\times$ 100 mesh (150 μm) classifying cyclone underflow at about 28–35 t/h. A continental progressing cavity pump, model 1CL4-CDF, was used to pump Orimulsion into the flotation concentrate for the plant-scale tests. The effective pumping range of this pump is 4–38 l/min.

The preliminary laboratory test results (Wen and Killmeyer, 1997) indicated that it was better to add the bitumen emulsion to the flotation concentrate before mixing with the cyclone underflow. Based on the Terry Eagle Plant flowsheet (Fig. 2), the addition

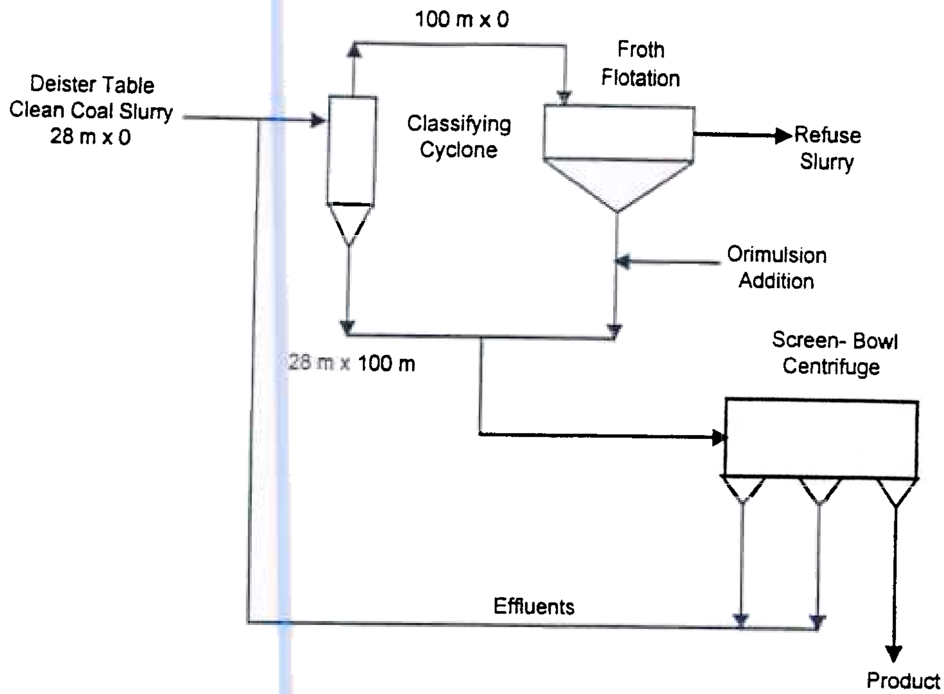

Fig. 2. Centrifuge dewatering flowsheet at the Terry Eagle plant.

of emulsion into the flotation concentrate would also provide a longer mixing time for the emulsion and coal particles, which should result in the formation of some larger coal agglomerates that would be beneficial for product moisture reduction. In addition, the flotation collector, which enhances the particle hydrophobicity, should also enhance the coal particle/emulsion attachment. According to FETC's chemical analysis of the centrifuge effluent reported from the different bituminous coals tested, all of the emulsion added to the flotation concentrate stayed with the agglomerated coal. This leaves no free emulsion to discharge with the effluent.

A total of 3000 l of emulsion was available. Based on the flotation concentrate flow rate of an average of 13.5 t/h, a 2-h test was conducted for the Terry Eagle plant. For each condition, the test lasted approximately 15 min.

3. Results and discussion

3.1. Effect of Orimulsion concentration on product moisture, and handleability

3.1.1. For pilot-scale tests at Mayflower plant

All test results are summarized in Table 1. Fig. 3 indicates that the average moisture contents of the dewatered coal were 35.7, 35.5, 32.6, 29.9, and 26.5 wt.% with Orimulsion additions of 0, 0.7, 3.2, 4.8, and 6.4 wt.%, respectively. In this series of tests, the product moisture reductions were superior to those obtained at FETC's 15-cm laboratory screen–bowl centrifuge when testing similar sizes of other coals, and were almost equivalent to results [illegible] FETC's 36-cm high-g solid–bowl centrifuge. This

Table 1
GranuFlow process testing results on column flotation concentrate from Mayflower plant (at 76 l/min feed rate, 15 wt.% slurry solids, 91 wt.% − 150 mesh, and 6.5 wt.% ash in slurry solids)

Orimulsion, wt.%	Product moisture, wt.%	Product ash, wt.%	Centrifuge effluent solids, wt.%	Centrifuge effluent ash, wt.%	Screen effluent solids, wt.%	Screen effluent solid ash, wt.%	Product dust index	Dust reduction efficiency, %
0	35.7	4.4	3.4	14.0	44.7	9.3	82	10
0.7	35.5	4.4	3.0	16.1	33.7	9.3	56	38
3.2	32.6	4.5	3.1	17.2	9.1	11.2	12	88
4.8	29.9	4.4	1.8	24.3	2.4	15.1	5	95
6.4	26.5	4.4	NA[a]	NA	3.1	11.8	2	98

[a]No sample.

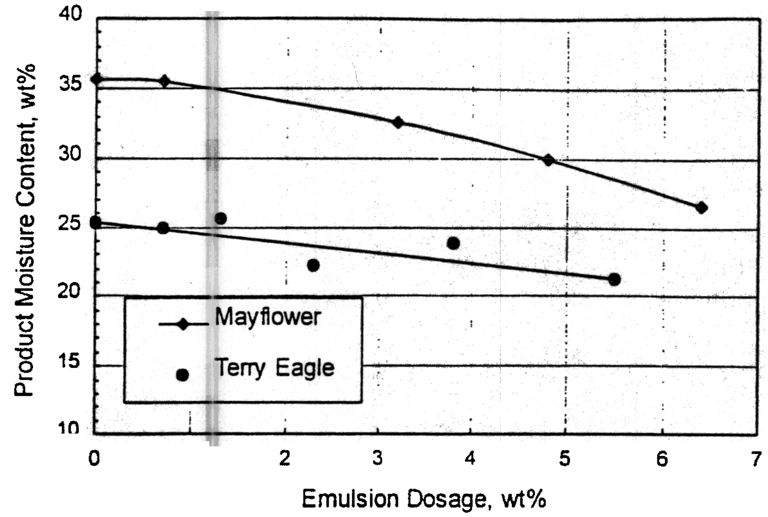

Fig. 3. Centrifuge product moisture contents Mayflower: a column flotation concentrate at -106 μm, 15 wt.% solids and 6.5 wt.% ash. Terry Eagle: a mixture of flotation concentrate plus cyclone underflow, at -600 μm, 9.6 wt.% ash.

could be due to the higher hydrophobicity of coal and the surface hydrophobicity generated by the flotation collector in the column flotation. Also, the size of the centrifuge, as a 46-cm centrifuge is more representative of a true industrial scale unit than a 15-cm lab-scale unit, and differences in centrifuge design contributed to this.

The handleability of the centrifuge product was greatly improved with the addition of Orimulsion. Free-flowing granules, as opposed to wet lumpy material, were clearly observed at an Orimulsion addition of 3.2 wt.% and above. The improved handleability of the product was also indicated by the formation of product piles discharged from the conveyer. During the tests, two product coal piles were formed under the conveyer. The primary discharge pile was formed at the very end of the conveyer belt due to free-falling coal-granules. The second discharge pile was formed under a conveyer scraper which was located about 30-cm underneath the end of conveyer belt. The Orimulsion-treated primary discharge pile exhibited a much smaller angle of repose than the untreated primary discharge coal pile. The angle of repose is the angle between the horizontal and the slope of a heap of material dropped from some elevation. The smaller the angle of repose, the more flowable is the material. Also, most of the Orimulsion-treated coal ended in the primary discharge pile, while most of the untreated coal ended in the secondary discharged pile.

3.1.2. For plant-scale tests at the Terry Eagle plant

All test results are summarized in Table 2. The product moisture contents shown in Fig. 3 indicate that this process was effective in reducing the moisture of ultrafine coal from 25 to 21 wt.% using a 5.5 wt.% bitumen dosage and a commercial screen–bowl centrifuge. The product was visibly drier on the conveyer belt with Orimulsion additions of 2 wt.% or more, and the handleability in terms of dust index was markedly improved. The Orimulsion addition not only reduced the product moisture content but also reduced

Table 2
GranuFlow Process test results on a 91 cm × 182 cm Bird screen–bowl centrifuge with a feed slurry of a mixture of flotation concentrate and cyclone underflow from the Terry Eagle plant (Centrifuge feed: −28 mesh (600 μm), with 10 wt.% ash, 35 wt.% solids)

Test no.	Orimulsion, wt.%	Product moisture, wt.%	Product ash, wt.%	Screen effluent solids, wt.%	Screen effluent solid ash, wt.%	Product dust index	Dust reduction efficiency, %
TE-P-1	0	25.3	9.3	31.1	12.2	59	–
TE-P-5	0.7	25.0	9.0	19.2	14.4	56	5
TE-P-3	1.3	25.6	9.5	12.1	15.5	19	68
TE-P-4	2.3	22.2	8.2	6.2	20.1	6	90
TE-P-6	3.8	23.8	8.4	4.9	20.2	3	95
TE-P-2	5.5	21.3	8.3	4.3	23.7	2	97
TE-P-7	0	25.8	9.3	31.6	12.1	59	–

the product ash content, which suggests that coal particles were selectively agglomerated.

3.2. *Effect of orimulsion treatment on product recovery, product ash, and effluent solids reductions*

3.2.1. *For pilot-scale tests at Mayflower plant*

The Orimulsion treatments dramatically reduced the solids content in both the screen effluent and centrifuge effluent. As a result, the dewatered coal recovery, as shown in Table 3, increased about 45 wt.% from 64.7 to 94.1 wt.% at Orimulsion dosages of 0 and 6.4 wt.%, respectively. The solids reduction in the centrifuge effluent alone accounted for about a 17.5 wt.% increase in the dewatered product at the Orimulsion dosage of 6.4 wt.%. The benefit of these solids reduction is threefold: (1) increased product recovery by 45 wt.%, (2) reduced polymer dosage in the waste slurry thickener by 70 wt.%, and (3) extended lifetimes of the slurry impoundment by more than 70%. Table 1 shows the product ash contents, and effluent ash and solids content. It is interesting to note that the average screen–bowl product ash content was 4.4 wt.%, which was much lower than the flotation product ash content of 6.5 wt.%. Evidently, centrifuge dewatering with Orimulsion provided some additional ash reduction. The results also indicated that the bitumen in the Orimulsion selectively agglomerated coal particles but not ash-forming particles, resulting in an increase in the effluent solids ash content and product recovery.

3.2.2. *For plant-scale tests at the Terry Eagle plant*

With increasing emulsion dosages from 0 to 5.5 wt.% as shown in Table 2, the screen effluent solids decreased dramatically from 31.1 to 4.3 wt.%, and the screen effluent solids ash content increased from 12.2 to 23.7 wt.%, respectively. Thus, the effectiveness of the process for screen effluent solids reduction is excellent. Fig. 4 shows screen effluent samples collected at each test condition. The color of the settled solids changed from dark black to light gray, and the quantity of solids visibly decreased as the Orimulsion dosage was increased. Due to the reduced solids content in the screen

Table 3
Approximate solids' balance for centrifuge products from the column flotation concentrate from the Mayflower plant (46-cm centrifuge at 1000 rpm and 226 g-force)

Orimulsion, wt.%	Solids balance, wt.%			
	Feed	Product	Centrifuge effluent	Screen effluent
0			22.5	
0.7			18.0	
3.2			14.7	
4.8			9.3	
6.4			8.0[a]	

[a]This data was estimated by using .8 wt.% of the centrifuge effluent solids at Orimulsion dosage of 4.8 wt.% in Table 1.

efficiency reached 97 and 98 wt.% at 4.8 and 6.4 wt.% Orimulsion additions, respectively.

3.3.2. For plant-scale tests at the Terry Eagle plant

The average dust indices of the Orimulsion treated dry products as also shown in Fig. 5 were 59, 56, 19, 6, 3 and 2 wt.% at Orimulsion dosages of 0, 0.7, 1.3, 2.3, 3.8, and 5.5 wt.%, respectively. Dust reduction efficiency as shown in Table 2 indicated that more than 90 wt.% of the dust was reduced by agglomeration at 2.3 wt.% Orimulsion.

3.4. Cost estimation

The cost of Orimulsion at a sea port in the southeastern US would be around US$40 per ton. When using a bitumen dosage around 6 wt.% (which is equivalent to an Orimulsion dosage of 8.6 wt.% because of its water content), this would add US$3.44 to each ton of fine-coal product treated. Approximately half of the cost of Orimulsion can be credited as additional salable calorie at the price of coal (~ US$25 per ton). Thus, the true cost may be US$2 per ton of fine coal. If this treated fine coal is about 10–20 wt.% of the coal shipment sold to a utility, the actual added cost per ton of shipped coal is around US$0.2–0.4. This cost estimation does not include transportation costs of Orimulsion to the preparation plant, which could be significant, depending on location. The major cost savings from using Orimulsion could come from (1) higher recovery of fine coal product, (2) less wind loss during transportation, (3) longer life times for waste impoundments, (4) elimination of thermal drying, (5) less need for dust suppressants or freeze conditioning agents (Wen and Killmeyer, 1996), (6) more salable and acceptable fine clean coal product, and (7) recovery of fine coal currently being disposed of.

3.5. Potential benefits in commercial applications

The GranuFlow Process has a variety of potential benefits, some of which may be more important than others depending on the particular application. Some commercial benefits are as follows: (1) increased amounts of fine coal can be added to utility plant feedstocks without creating handling problems; (2) the top size of coal fed to a preparation plant can be reduced to take advantage of increased liberation in order to improve the quality of the clean-coal product; (3) coal fines (valuable fuel) can be reclaimed from waste ponds with an attendant cleanup of waste sites, and (4) handleability during transportation can be improved by alleviating dust and freezing problems.

4. Conclusions

The GranuFlow Process was successfully demonstrated in both pilot-plant-scale and plant-scale tests at the Mayflow and Terry Eagle plants. The process improved product handleability by converting wet sticky fines into granular, free-flowing materials with decreased moisture content, decreased dustiness, and increased solids recovery of the final product.

Fig. 4. Screen effluent samples (Orimulsion dosages from left to right: 0, 0.7, 1.3, 2.3, 3.8, and 5.5 wt.%).

effluent, the product coal recovery is increased. The baseline tests (0% Orimulsion), which were performed at the beginning and end of testing, were consistent with one another and indicated no evidence of screen plugging.

3.3. *Effect of Orimulsion concentration on product dust index*

3.3.1. *For pilot-scale tests at Mayflower plant*

The dust index of the feed coal, I_0, was 91 wt.% passing 150 mesh (106 μm) obtained from a wet screen analysis. The average dust indices of the Orimulsion treated dry product, as shown in Fig. 5, were 82, 56, 12, 5, and 2 wt.% using Orimulsion dosages of 0, 0.7, 3.2, 4.8, and 6.4 wt.%, respectively. Dust reduction efficiency as shown in Table 1 indicated that more than 85 wt.% of the dust (material finer than 150 mesh) was reduced by agglomeration at 3.2 wt.% Orimulsion. The dust reduction

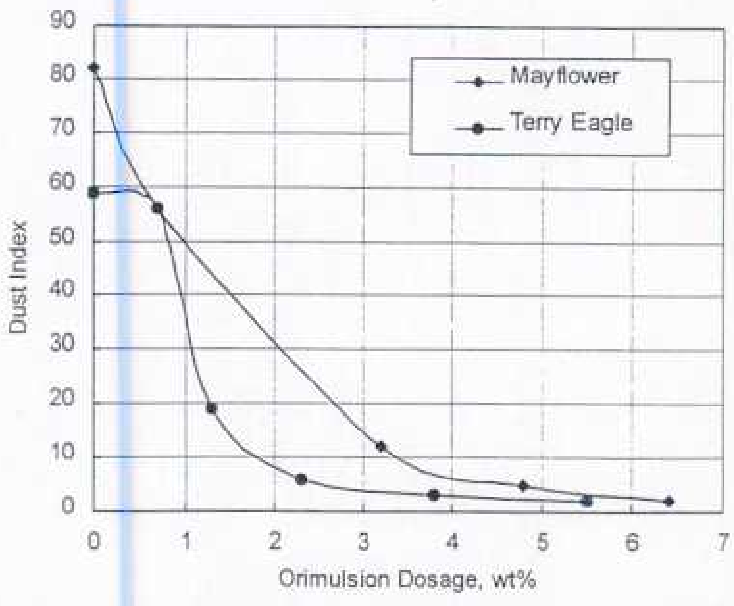

Fig. 5. Product dust index vs. emulsion concentrations of the GranuFlow Process of the pilot-scale tests (Mayflower) and the plant-scale tests (Terry Eagle).

This technology has been proven to be a viable process that can alleviate the coal producers' current practice of discarding coal fines, and can reclaim existing coal waste ponds.

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